ECOSYSTEM SERVICES BY TREES OUTSIDE FOREST: SHOULD THE STRUCTURE AND LOCATION OF NEW PLANTINGS MATTER MORE?

Zajączkowski J

Correspondence author: jacek_zajaczkowski@sggw.pl

Department of Silviculture, Warsaw University of Life Sciences (SGGW),
02-787 Warszawa, Nowoursynowska 159 Bldg. 34, Poland

Introduction

Several hundred million trees nad shrubs have been planted throughout Polish agricultural land during last 60 years, which opened wide research opportunities on ecosystem services they provide and the best practices on structural and spatial features design for new plantings.

Woody belts and patches scattered among fields and small settlements, along roads, railways, rivers and lakes proved to be a valuable tool to mitigate large-scale phenomena negatively influencing natural environment, economic activities and human well-being. Such environmental problems of modern agriculture include biodiversity loss, water erosion and contamination, wind-induced soil erosion, excessive evapotranspiration and snow transport, as well as insufficient crop pollination and natural pest resistance.

A broad, ecology oriented definition of woody patches outside forests, which was elaborated in 1982 to face the above findings and was adopted in Polish Nature Protection Act, goes *"trees and shrubs scattered in the agricultural landscape, growing in groups, rows, belts or as isolated individuals, not forming forest communities, along with the ground they cover and other components of vegetation"*.

Because different spatial and compositional structures of trees outside forests represent diverse capabilities to mitigate environmental threats or deficits, practical classification of their main features has been elaborated to ease proper design of new plantings. Compositional features include 1) species compostion, calculated as percentage from specimen numbers, 2) vertical structure, describing presence of separate crown layers - first and second tree floor, and/or shrub understory, and 3) tree and shrub planting distances, which result in different crown densities.

From spatial perspective, patches differ by unit area, shape, direction and type of management or topography on surrounding land. Patch area is determined according to crown vertical coverage of its woody vegetation, or - in special case of wild pollinators' nesting places - as area covered mainly by wild now-woody perennials. Distinct patch spatial forms set apart in Polish conditions include: 1) singletons - dispersed in distances from nearest neighbour exceeding 50 m for trees or 15 m for shrubs, on which mutual influence becomes negligible, 2) small groups, with unit area 0.02-0.10 hectare, 3) large groups – irregularly shaped areas above 0.10 ha, but not capable to form autonomous forest interior, 4) lines – tree and/or shrub rows or double-row avenues, 5) belts -elongated multirow shapes with maximum length being at least 5 larger than average witdh.

Geographical orientation of lines and belts matters much for future shadowing problems and ability to mitigate winds on their most frequent directions. According to surrounding land type, patches may be classified to agricultural land (arable, meadow, pasture), communication areas (motor- and railways, or their accompanying small infrastructure), open water banks (rivers, canals, lakes, ponds, drainage ditches), small industry objects (plants, excavation holes and landfills), as well as local settlement and recreation areas.

Methods

Identification of most important environmental hazards, which negatively influence crop yields and ecosystem stability in Polish agricultural landscapes, was compiled from results of research projects conducted by Institute for Agricultural and Forest Environment in Poznań, Forest Research Institute in Sękocin and Agricultural University in Lublin. Ecosystem services of different woody structures within open landscape, related to their mitigating potential against diverse environmental threats, were selected and analysed.

For each ecosystem service selected, basic guidelines on preferred spatial features, species composition and vertical structure of woody patches were presented, which have been suggested by other authors as result of long-term professional practice and research. Discussion on mitigating efficiency loss was also presented for cases violating the these guidelines.

Results

Environmental hazards which trees outside forest may mitigate

Biodiversity loss on agricultural land is long-lasting and wide-recognized process. Rare reptile, amphibian and other wild animal and plant species still inhabit fields in Poland as result of weaker agriculture development under long lasting (until 1988) socialist economy. The more homogenous becomes landscape of modern agriculture, the larger overall species loss and larger animal species biomass fraction is formed by herbivorous pests, at cost of their predators or parasites, which were able to keep pest outbreaks under control in former, more natural environments. These useful animal species usually need uncultivated and vegetation-covered patches, especially of elongated shape, to migrate, feed and nest. Starting from such safe and rich refuges, small predatory mammals, birds, insects and fungi may control pest outbreaks on nearby fields. The effective distance of such control depends on species, and usually does not exceed 300 m. About 400 useful wild bee species and subspecies, which find most favourable nesting conditions in warm soils on patches covered with scarce wild vegetation, are unique pollinators of *ca* 60 species of seed crops, including rape for oil, legumes as secondary crops, cultivated fruit plants *etc*., which cover 20% of cultivated area in Poland.

Water loss due to evapotranspiration and surface runoff has become a crucial factor limiting agricultural production on sandy soils of Polish lowland. Maize and sugar beet, species lacking access to spring water resources due to late seasonal growth, may suffer up to 50% yield reduction until 2100 according to estimations made for future climate projections. Long drought periods occur several times within each decade and are expected to become more frequent, making farm management more risky and less effective. As evapotranspiration depends on wind speed close to the ground, rows and belts of trees may be effectively used to decrease it by ca. 70 mm, even taking into account their higher transpiration. This resulted in 5-15% crop yield increment in some field experiments on cereals. The lenght of diminished wind speed zone (at least by 10%) is proportional to tree barrier height *h*. It may reach up to 20*h* (500 m) in most favourable conditions of barrier direction (perpendicular to prevailing wind direction), crown density (moderate, 60-70% opacity counted from wind direction) and terrain topography (best locations on plains or flat hill tops). Tree barriers protect soil water resources more effectively in winters, counteracting soil deep freezing and blowing snow away from fields. Soils under wild vegetation develop rich humus layer, which forces surface waters from storms or snow melting to soak, thus stopping water runoff losses. If barrier effect is expected out of season, when broadleaved species lack leaves and wind mitigating ability of crowns drops *ca* two-fold, wider belt forms or evergreen species admixture should be preferred.

Wind soil erosion is another wind-caused problem on larger (>10 ha) fields of fine grained soils, occuring mostly during winter frosts in absence of snow cover. Blowing away humus, top soil layers and fertilizers decreases soil fertitility and water retention ability.

Water erosion appears on slopes in hilly or montainous regions and results in washing away upper, usually humus-rich and most fertile soil layers. The erosion risk depends on slope factor (usually starting from 6-10%), soil granulation (homogenous thin particles, as in loess soils, ease erosion), and land management type, being most significant on arable lands, and negligible on most areas of permanent grass cover. Water erosion occurs also on abandoned excavation places and other wastelands of variable topography, which should be considered as potential safe refuges of high biological value. On ravine and river banks, experiencing high energy water erosion, trees and shrubs are needed to anchor grass cover with their deeper roots.

Ground and open water contamination by fertilizers applied on fields is difficult to challenge due to weak cultivated soil absorption capability. Wild vegetation on non-cultivated field margins stops surface water runoff and uptakes dissolved nutrients. The mean water purifying effectiveness of properly designed biological barriers exceeds 60%, and reaches outstanding 96% in case of nitrogen. This enables keeping high agricultural production while retaining biologically rich environment with high level of ecosystem services.

Design and location guidelines for new plantings

Practical observations on tree barrier effects have given three general conclusions: 1) only large barrier systems, multiplicated on areas of at least several square kilometeres, may mitigate environmental threats in vast agricultural landscapes, 2) spatial orientation of barrier must be adjusted to directional threats, as wind-induced erosion and evapotraspiration or gravitational water runoff-induced erosion and contamination, and 3) old barriers gradually lose their wind mitigating ability due to crown decomposition, which also makes management problems on nearby fields or roads, and should be replaced by new ones. The suggested replacing age varies from 40 years for poplars to 80-100 years for other tree species, except from oak, lime and ash, usually featuring higher longevity.

Wind-mitigating barriers will be most effective on distances of 12-18*h*, depending on water deficit severity, which is of greater concern on sandy soils. Too dense barrier spacing may result in crop production loss due to excessive shadowing or air humidity-induced crop pest infections. Tree barrier intercepts wind energy best at angle between wind and barrier direction fitting in 60-120º range. To keep barrier mitigating potential at other wind angles, secondary barriers should be added perpendicularly to main barriers. They may have more scarce spacing and lower final height. Example schema of barrier system is given on Figure 1. The vertical structure of main barriers should be composed of one high tree species of large, regular shape crown and break-resistant trunk and root system, accompanied by shrub belt filling open space beneath tree crowns and stopping nozzle effect. Crown leaf density (relative opacity from horizontal perspective) depends on main season of expected mitigating acitivity: for summer operations it should not exceed 60-70%, and may be higher for winter operating barriers, which should also have more dense spacing and greater width. Both too high and too low crown density will result in significant shortening of effective mitigating range. Barriers located near hill tops would have greater wind mitigating effect than those established on slopes or in valleys.

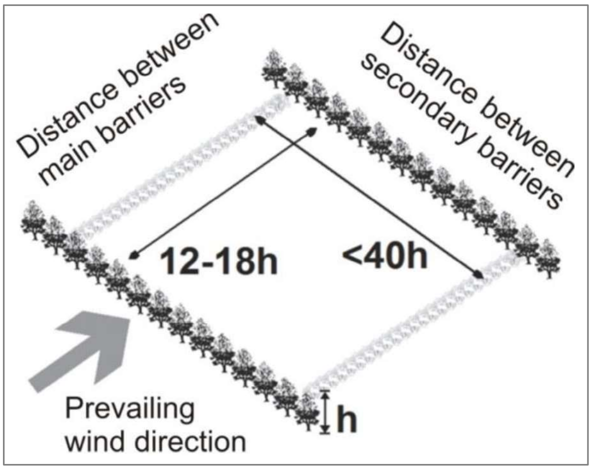

Figure 1: Optimum spatial orientation and distances for tree barrier systems designed to mitigate wind-induced evapotranspiration on crop fields

Woody areas designed to minimize water erosion should be located on upper parts of hills and ravines, paralelly to terrain contour lines, and also on natural river banks. They should be covered with grass vegetation and scarcely spaced trees and/or shrubs species giving low shadow. Patches designed to minimize water contamination should be located paralelly to banks of open water, preventing water with fertilizers from surface and in-depth leakage, which occurs especially on slopes and in case no artificial embankments are build. The barrier optimum width depends on land-use type: arable fields cause the greatest contamination risk and shpuld result in the widest, up to 10 m non-cultivated grassy belts with loosely spaced trees.

Patches and belts designed to enhance agricultural landscape's biological richness and self-regulation ability should form net-shaped structure with base diameter *ca* 500 m. This net should be biuld of continuous shrub layer and sparse trees of native species. The significant share is expected of large size, old living trees, standing and fallen dead wood, as well as fruity and thorny shrub species. Low density and moderate maximum height of trees are suggested design rules to minimize adjacent field shadowing and enhance frutification. Open areas may be left inside or on warm margins of larger patches in net nodes, to make feeding or nesting areas for the game and thermophilous wild bees, spiders and other insects. Single trees may be left inside larger net openings, as stepping stones for migrating birds and mammals.

A set of woody plant species and production cultivars was selected by interdisciplinary team to enable species composition optimisation for new plantings in Poland. Applicability assessment was made for *ca* 100 species, regarding three groups of issues: 1) site preferences - soil types, light and water conditions, 2) expected tree functions, related to environment threats mitigation, utility services and human well-being enhancement, and 3) preferred spatial forms and locations. Figure 2 gives example screen of simple web service EKSPERT, which was developed to ease information perception on suggested applicability class (full, conditional or none).

Conclusions

The above giudelines show multidimensional relationships among trees outside forest spatial and structural features and their mitigation effectiveness against environmental factors negatively influencing yield stability of agricultural crops.

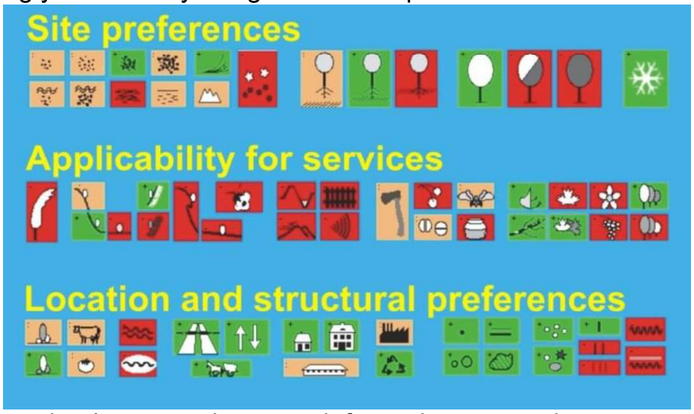

Figure 2: Graphics and colours used to ease information perception on example screen of web service aiding species selection for new woody patches establishment in agricultural landscape. Data for species Silver birch *Betula pendula.* Green background and '+' mark denotes full apllicability for given criteria, orange and ':" – partial, red and '-' – no applicability. Polish tooltips on criteria names available under cursor pointer on web page

Public financial support on environment protection in agriculture would have become more effective, if any incentives directed on retaining and/or developing woody vegetation within agricultural landscape were preceded by recognition of potential ecosystem services which they might provide, and also by project of optimum spatial and structural features for new plantings. Obligatory incorporation of such recognition activity in land-use planning regulations has being postulated by Polish scientific society since 1980-ties.
Current European Union regulations on greening policy and agroforestry generally lack promotion of structural and spatial features of such wooded field margins, except of water buffer zones.
Future law developments should be directed on increasing large-scale mitigating efficiency of trees outside forests, which would be followed by new profits from crop yield and its long-term stabilization, as well as increased biological diversity and aesthetic values of agricultural landscapes.

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